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"Resonator structure"
(Resonaattorirakenne)

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Resonator structure
Resonaattorirakenne
Resonatorstruktur

The invention relates in general to filters and resonators. The invention relates in particular to piezoelectric resonators.

The development of mobile telecommunications continues towards ever smaller and increasingly complicated handheld units. The development leads to increasing requirements on the miniaturization of the components and structures used in the mobile communication means. This development concerns radio frequency (RF) filter structures as well, which despite the increasing miniaturization should be able to withstand considerable power levels, have very steep passband edges, and low losses.

The RF filters used in prior art mobile phones are usually discrete surface acoustic wave (SAW) or ceramic filters. Surface acoustic wave (SAW) resonators typically have a structure similar to that shown in Figure 1. Surface acoustic resonators utilize surface acoustic vibration modes of a solid surface, in which modes the vibration is confined to the surface of the solid, decaying quickly away from the surface. A SAW resonator typically comprises a piezoelectric layer 100, and two electrodes 122, 124. Various resonator structures such as filters are produced with SAW resonators. A SAW resonator has the advantage of having a very small size, but unfortunately cannot withstand high power levels.

It is known to construct thin film bulk acoustic wave resonators on semiconductor wafers, such as silicon (Si) or gallium arsenide (GaAs) wafers. For example, in an article entitled "Acoustic Bulk Wave Composite Resonators", Applied Physics Letters, Vol. 38, No. 3, pp. 125-127, Feb. 1, 1981, by K.M. Lakin and J.S. Wang, an acoustic bulk wave resonator is disclosed which comprises a thin film piezoelectric layers of zinc oxide (ZnO) sputtered over a thin membrane of silicon (Si). Further, in an article entitled "An Air-Gap Type Piezoelectric Composite Thin Film Resonator", I5 Proc. 39th Annual Symp. Freq. Control, pp. 361-366, 1985, by Hiroaki Satoh, Yasuo Ebata, Hitoshi Suzuki, and Choji Narahara, a bulk acoustic wave resonator having a bridge structure is disclosed.

Figure 2 shows one example of a bulk acoustic wave resonator having a bridge structure. The structure comprises a membrane 130 deposited on a substrate 200. The resonator further comprises a bottom electrode 110 on the membrane, a piezoelectric layer 100, and a top electrode 120. A gap 210 is created between the membrane and the substrate by etching away some of the substrate from the top side. The gap serves as an acoustic isolator, essentially isolating the vibrating resonator structure from the substrate.

Bulk acoustic wave resonators are not yet in widespread use, partly due to the reason that feasible ways of combining such resonators with other circuitry have not been presented. However, BAW resonators have some advantages as compared to SAW resonators. For example, BAW structures have a better tolerance of high power levels.

In the following, certain types of BAW resonators are described first.

Bulk acoustic wave resonators are typically fabricated on silicon (Si), gallium arsenide (GaAs), glass, or ceramic substrates. One further ceramic substrate type used is alumina. The BAW devices are typically manufactured using various thin film manufacturing techniques, such as for example sputtering, vacuum evaporation or chemical vapor deposition. BAW devices utilize a piezoelectric thin film layer for generating the acoustic bulk waves. The resonance frequencies of typical BAW devices range from 0.5 GHz to 5 GHz, depending on the size and materials of the device. BAW resonators exhibit the typical series and parallel resonances of crystal resonators. The resonance frequencies are determined mainly by the material of the resonator and the dimensions of the layers of the resonator.

A typical BAW resonator consists of three basic elements:
- an acoustically active piezoelectric layer,
- electrodes on opposite sides of the piezoelectric layer, and
- acoustical isolation from the substrate.

The piezoelectric layer may be for example, ZnO, AlN, ZnS or any other piezoelectric material that can be fabricated as a thin film. As a further example, also ferroelectric ceramics can be used as the piezoelectric material. For example, $PbTiO_3$ and $Pb(Zr_xTi_{1-x})O_3$ and other members of the so called lead lanthanum zirconate titanate family can be used.

Preferably, the material used to form the electrode layers is an electrically conductive material having a high acoustic impedance. The electrodes may be comprised of for example any suitable metal, such as tungsten (W), aluminum (Al), copper (Cu), molybdenum (Mo), nickel (Ni), titanium (Ti), niobium (Nb), silver (Ag), gold (Au), and tantalum (Ta). The substrate is typically composed of for example Si, SiO_2, GaAs, glass, or ceramic materials.

The acoustical isolation can be produced with for example the following techniques:
- with a substrate via-hole,
- with a micromechanical bridge structure, or
- with an acoustic mirror structure.

In the via-hole and bridge structures, the acoustically reflecting surfaces are the air interfaces below and above the devices. The bridge structure is typically manufactured using a sacrificial layer, which is etched away to produce a free-standing structure. Use of a sacrificial layer makes it possible to use a wide variety of substrate materials, since the substrate does not need to be modified very much, as in the via-hole structure. A bridge structure can also be produced using an etch pit structure, in which case a pit has to be etched in the substrate or the material layer below the BAW resonator in order to produce the free standing bridge structure.

Figure 3 illustrates one example of various ways of producing a bridge structure. Before the deposition of other layers of the BAW structure, a sacrificial layer 135 is deposited and patterned first. The rest of the BAW structure is deposited and patterned partly on top of the sacrificial layer 135. After the rest of the BAW structure is completed, the sacrificial layer 135 is etched away. Figure 3 shows also the substrate 200, a membrane layer 130, the bottom electrode 110, the piezoelectric layer 100, and the top electrode 120. The sacrificial layer can be realized using for example a metal or a polymer as the material.

In the via-hole structure, the resonator is acoustically isolated from the substrate by etching away the substrate from under a major portion of the BAW resonator structure. Figure 4 illustrates a via-hole structure of a BAW resonator. Figure 4 shows the substrate 200, a membrane layer 130, the bottom electrode 110, the piezoelectric layer 100, and the top electrode 120. A via-hole 211 has been etched through the whole substrate. Due to the etching required, via-hole structures are commonly realized only with Si or GaAs substrates.

A further way to isolate a BAW resonator from the substrate is by using an acoustical mirror structure. The acoustical mirror structure performs the isolation by reflecting the acoustic wave back to the resonator structure. An acoustical mirror typically comprise several layers having a thickness of one quarter wavelength at the center frequency, alternating layers having differing acoustical impedances. The number of layers in an acoustic mirror is typically an odd integer, typically ranging from three to nine. The ratio of acoustic impedance of two consecutive layers should be large in order to present as low acoustic impedance as possible to the BAW resonator, instead of the relatively high impedance of the substrate material. In the case of a piezoelectric layer that is one quarter of the wavelength thick, the mirror layers are chosen so that as high acoustic impedance as possible is presented to the resonator. This is disclosed in US patent 5 373 268. The material of the high impedance layers can be for example gold (Au), molybdenum (Mo), or tungsten (W), and the material of the low impedance layers can be for example silicon (Si), polysilicon (poly-Si), silicon dioxide (SiO_2), aluminum (Al), or a polymer. Since in structures utilizing an acoustical mirror structure, the resonator is isolated from the substrate and the substrate is not modified very much, a wide variety of materials can be used as a substrate. The polymer layer may be comprised of any polymer material having a low loss characteristic and a low acoustic impedance. Preferably, the polymer material is such that it can withstand temperatures of at least 350 °C, since relatively high temperatures may be achieved during deposition of other layers of the acoustical mirror structure and other structures. The polymer layer may be comprised of, by example, polyimide, cyclotene, a carbon-based material, a silicon-based material or any other suitable material.

Figure 5 shows an example of a BAW resonator on top of an acoustical mirror structure. Figure 5 shows the substrate 200, the bottom electrode 110, the piezoelectric layer 100, and the top electrode 120. The acoustical mirror structure 150 comprises in this example three layers 150a, 150b. Two of the layers 150a are formed of a first material, and the third layer 150b in between the two layers is formed from a second material. The first and second materials have different acoustical impedances as described previously. The order of the materials can be varied. For example, the material with a high acoustical impedance can be in the middle and the material with a low acoustical impedance on both sides of the middle material, or vice versa. The bottom electrode may also be used as one layer of the acoustical mirror.

Figure 6 shows a further example of a BAW resonator structure. The BAW resonator illustrated in Figure 6 is a stacked resonator structure having two piezoelectric

layers 100. In addition to the bottom 110 and top 120 electrodes, a stacked structure requires a middle electrode 115, which is connected to ground potential. Figure 6 further shows the membrane layer 130, the substrate 200 and the etch pit 210 isolating the structure from the substrate.

One of the desired properties of a filter is that at the frequencies which the filter passes, the response of the filter is as even as possible. The variations in the frequency response are called the ripple. The frequency response of a filter should thus be constant, for example in a bandpass filter, over the bandwidth of the filter. In the blocking frequencies the ripple is usually not a problem. In filters that are constructed using many crystal resonators or, for example BAW resonators, the ripple is at least partly caused by spurious resonance modes of the crystal resonators. Term spurious resonance refers here to resonance frequencies that are not the design resonance frequency of the resonator.

The cut-off frequency for a resonator is determined by assuming that the crystal resonator consists of infinite planes of conducting material and of an infinite piezoelectric layer in between the conducting planes. The cut-off frequency is thus determined directly by the material of the planes and by the thickness of the planes. In an infinite plane there are no lateral resonance modes. The lateral dimensions of the resonator (or any plate) cause lateral resonance modes to emerge, and the basic resonance frequency of a resonator or that of a plate that is related to the first mode lateral resonance is somewhat higher than the cut-off frequency. The lateral dimensions of the resonator thus affect the value of its basic resonance frequency.

In a plate there can be various mechanical vibrations. Certain lateral resonance modes may be excited pietzoelectrically, when an alternating voltage is exerted over the crystal. The basic lateral resonance mode corresponds to a situation, where there is an amplitude maximum in the middle of the crystal plane. Any lateral resonance modes can be excited mechanically, but only the odd harmonic frequencies can be excited pietzoelectrically. These lateral resonance modes that are usually at different frequencies cause the surface of the resonator to oscillate.

The problem with the lateral resonance modes is that the spurious resonances of a resonator are at least partly due to these lateral resonances. This is discussed, for example, in an article entitled "Thin film bulk acoustic wave filters for GPS", in 1992 Ultrasonic Symposium, pp. 471-476, by K. M. Lakin, G. R. Kline and K. T. McCarron. The lateral resonance modes deteriorate the properties of systems that comprise

of crystal resonators. The ripple in a frequency response of a filter is one example of the effect of the spurious resonance.

An object of the invention is to provide a resonator structure where the effect of the lateral waves has been suppressed. A further object of the invention is provide a resonator structure that is easy to manufacture.

The object of the invention is achieved by modifying the layer structure of the resonator in a frame-like zone around the center of the resonator.

A resonator structure according to the invention is a structure comprising two conductor layers and a piezoelectric layer in between the conductor layers, and it is characterized in that
- the resonator structure further comprises a frame-like zone which confines a center area,
- the center area is within the active area of the resonator and
- the frame-like zone is acoustically different from the center area.

A filter according to the invention is a filter comprising at least one resonator structure, which comprises two conductor layers and a piezoelectric layer in between the conductor layers, and it is characterized in that
- the resonator structure further comprises a frame-like zone which confines a center area,
- the center area is within the active area of the resonator and
- the frame-like zone is acoustically different from the center area.

Mobile communication means according to the invention are communication means comprising at least one resonator structure, which comprises two conductor layers and a piezoelectric layer in between the conductor layers, and it is characterized in that
- the resonator structure further comprises a frame-like zone which confines a center area,
- the center area is within the active area of the resonator and
- the frame-like zone is acoustically different from the center area.

A resonator structure according to the invention comprises two conductive layers and a piezoelectric layer between the conductive layers. The conductive layers form

the electrodes of the resonator. The piezoelectric layer may be a piezoelectric crystal or it may be a thin-film layer of piezoelectric material.

The active area of a resonator is that area to which both the conducting layers extend. Usually it is in the middle of a resonator. In a resonator structure according to the invention, there is a frame-like zone that encircles a center area of the resonator. Term center area refers here to the area inside the frame-like zone. It does not have to be, for example, in the center of the resonator area. The center area is within the active area of the resonator. The acoustical properties of the frame-like zone are different from those of the center area. The acoustical properties of a structure comprise at least the acoustical thickness of a structure and how effectively vibrations are dampened in the structure. The frame-like zone may be inside the active area or it may be at least partly outside the active area.

Acoustical thickness of a certain structure is here defined by the cut-off frequency of an infinite plane that has the same layer structure as the studied structure. Acoustically thicker usually implies that the structure is also physically thicker, but this is not always the case.

The acoustically different frame-like zone around the center area of the resonator can be easily constructed by, for example, letting two layers, one of which extends over the center area and the other does not, to overlap around the center area. The area where the two different layers overlap is the acoustically thicker frame-like zone. It is acoustically thicker than the center area, because compared to the center area it has additional layers. If the material of the layer, which does not cover the center area, is selected so that it dampens vibrations, then the acoustically different frame-like zone also dampens vibrations more effectively than the center area.

By choosing the width and thickness of the acoustically different zone properly, the lateral resonance modes in the center area can be controlled. How to choose the dimensions is discussed in more detail in connection with the preferred embodiments of the invention. It is possible to obtain in the active area a piston mode resonance, which means that the center area of the resonator vibrates at the cut-off frequency. In this optimal case, the frame-like zone causes the center area to see itself as infinite. Even if the piston mode is not reached, the frame-like zone suppresses the higher order lateral frequency modes so that the wave in the center area has a smoother amplitude distribution. A relatively larger part of the wave of higher order lateral resonance modes than of the first order lateral resonance mode is confined to

the edge of the active area. Therefore modification of the properties of the edge of the active area affects more the higher order lateral resonance modes.

It is possible to modify both the mechanical behavior and the piezoelectric properties of the frame-like zone. If the frame-like zone is not covered by both electrodes of the resonator, then it affects only the mechanical behavior of the resonator. If it is at least partly covered by both electrodes of the resonator, then also the piezoelectric properties are affected. The lateral resonances in the active area can be controlled better, if the acoustically thicker frame-like zone is partly overlapping with the active area. Advantageously the active area is the combination of the center area and the frame-like zone.

The frame-like zone is preferably constructed by causing different layers to overlap near the edge of the active area. It is also possible to add one or more frame-like layers to the resonator structure. The frame-like layer may locate, for example, on the top electrode, or it may be between the electrodes. Other ways to modify the acoustic thickness of the layer structure comprise modifying the thickness of the layers around the active area. The material that is used to increase the acoustical thickness of the frame-like zone can be conducting or dielectric. The material may or may not attenuate vibrations.

The shape of the active area of the resonator or that of the center area is not restricted to any particular shape in a resonator structure according to the invention. The width and acoustical properties of the frame-like zone are advantageously substantially constant throughout the frame-like zone, but the resonator structures according to the invention are not restricted to such structures comprising a frame-like zone with uniform layer structure.

The resonator structure according to the invention enhances the properties of conventional crystal resonators and especially the properties of thin-film BAW resonators. The properties of the prior-art BAW resonator types can be enhanced by modifying the structures according to the invention. Further, when the properties of the resonators are enhanced, the properties of the components that comprise resonators are improved. Specifically, it is advantageous to manufacture filter using the resonator structures according to the invention. Such filters may be used, for example, in mobile communication devices.

The invention will now be described more in detail with reference to the preferred embodiments by the way of example and to the accompanying drawings where

Figure 1 illustrates a surface acoustic resonator according to prior art,

Figure 2 illustrates a bulk acoustic wave resonator according to prior art,

Figure 3 shows another bulk acoustic wave resonator structure having a bridge structure,

Figure 4 illustrates a bulk acoustic wave resonator having a via-hole structure,

Figure 5 illustrates a bulk acoustic wave resonator isolated from the substrate by an acoustic mirror structure,

Figure 6 illustrates a stacked bulk acoustic wave resonator,

Figure 7 illustrates a resonator structure according to a first preferred embodiment of the invention,

Figure 8 shows the response of a resonator structure according to the first preferred embodiment of the invention on Smith's chart,

Figure 9 illustrates a resonator structure according to a second preferred embodiment of the invention,

Figure 10 shows the response of a resonator structure according to the second preferred embodiment of the invention on Smith's chart and

Figure 11 illustrates a resonator structure according to a third preferred embodiment of the invention.

Above in conjunction with the description of the prior art reference was made to Figs. 1-6. The same reference numerals are used for corresponding parts in the figures.

Fig. 7 illustrates a resonance structure 700 according to a first preferred embodiment of the invention. The resonance structure in Fig. 7 is by the way of example a BAW

resonator and it comprises a bottom electrode 701 and a top electrode 702. In between these electrodes there is a piezoelectric layer 703. The BAW resonator may be constructed, for example, over an acoustic mirror or using a bridge structure.

The horizontal and vertical dimensions in Fig. 7 are not in scale. Typical width of a BAW resonator is about 300 μm, the thickness of the piezoelectric layer 703 is typically some micrometers, the thickness of the conducting layers 701 and 702 is typically 400 nm.

The acoustically thicker frame-like zone is constructed to the resonator structure 700 by covering the piezoelectric layer 703 with a passivation layer 704. The passivation layer is dielectric material, and it both insulates the component electrically and protects the piezoelectric material. The passivation layer is opened (or removed by etching) where the top electrode 702 is to be placed. As can be seen in Fig. 7, the passivation layer and the conducting layer that form the top electrode overlap at the edge of the top electrode. The zone, where both the top electrode and the passivation layer extend, is a frame-like zone whose acoustical thickness is larger than that of the center of the resonator. In the resonator structure presented in Fig. 7, the acoustically thicker frame-like zone is on the active area of the resonator.

To add the frame-like structure on top of the resonator by using the overlapping passivation layer and top electrodes requires only slight changes to the manufacturing of the resonator structure. This method is thus easy and efficient for producing good quality resonators.

In this first preferred embodiment of the invention, the material used to form the frame-like zone is dielectric. It is also possible to make the frame-like zone, for example, by making the top electrode thicker at the edge.

The middle part of Fig. 7 presents a top view of the resonator structure 700. Line 730 presents the edge of the bottom electrode. The active area is the area which both the top electrode 702 and the bottom electrode 701 cover. The top electrode 702 extends to one direction outside the active area. Line 740 presents the area where there is no passivation layer 704.

The lower part of Fig. 7 presents also a top view of the resonator structure 700. it illustrates the frame-like zone 710 that confines the center area 720. The active area of the resonator structure 700 is the combination of the frame-like zone 710 and the

center area 720 where there is no passivation layer. In the resonator structure 700 the frame-like zone is within the active area.

To suppress the resonances of the lateral waves effectively in the center area of the resonator, the width w and thickness d of the frame-like zone can be chosen, for example in the following iterative way. The frequency of the first lateral resonance mode of a infinitely long slab, whose width is $2w$ and the layer structure is the same as in the frame-like zone, is calculated. The frequency can be determined straightforwardly, for example, using finite element method (FEM), when the materials and the thicknesses of the layers are known. The parameter w and the thickness d of the frame-like zone are adjusted so that basic lateral resonance mode of the slab is at a frequency that is the cut-off frequency of the center area of the resonator. Using these values in constructing a frame-like zone to a piezoelectric resonator produces practically the best possible resonance mode, without spurious resonances. It is also possible to use other width and thickness for the frame-like zone, for example such that are determined as specified above except that the higher lateral resonance modes of the frame-like zone are studied, but they do not suppress the lateral resonance modes in the center area as effectively.

The lateral wave in a resonator structure where the thickness and width of the frame-like layer have been chosen in the above manner is the following. In the area of the frame-like zone, the amplitude of the standing wave increases towards the central zone until a maximum is reached at the border of the frame-like zone and the central zone (i.e. there is half a node in the frame-like zone, and a small part of the wave leaks out from the outer edge of the frame-like zone). In the center area, the wave amplitude stays practically constant at the level it reaches at the border. The center area of the resonator operates in a piston mode.

In the frame-like zone there may be some lateral waves, but because the area of the frame-like zone is advantageously small compared to the center area, the effect of the lateral waves is most probably negligible.

The frame-like zone may be outside the active resonator area. If it is outside the active resonator area, then it modifies only the mechanical properties of the resonator. If the frame-like layer is at least partly covered by the electrodes, the frame-like zone contributes also to the piezoelectric properties of the resonator. The result is stronger suppression of the lateral resonance modes than when just the mechanical properties of the resonator are modified.

It is possible to place the material that makes the frame-like zone acoustically thicker between any layers of the resonator structure. Similar overlapping layers as Fig. 7 presents may be situated, for example, symmetrically in the vertical direction. The place of the additional layers may be determined, for example, by the ease of manufacturing the resonator. The width and thickness of a frame-like layer, for example, may depend on its place in the layer structure, but the FEM calculation, for example, may always be used to calculate the desired width and thickness of the frame-like layer.

Fig. 8 illustrates on Smith's chart the behavior of two BAW resonators. Smith's chart is a way to present the impedance of a certain electrical component as a function of the frequency. When calculating Smith's chart in Fig. 8, the impedance of the BAW resonators has been compared to a typical 50 Ω impedance.

In Smith's chart, frequency increases in a clockwise manner. A resonator which resonates only in the basic resonance mode produces a circle on Smith's chart. Possible loops in the diagram indicate spurious resonance frequencies.

In Fig. 8 shows the measured response of two resonators. The resonator, whose response is presented with a solid line 801, is a typical prior-art BAW resonator employing an acoustical mirror. The piezoelectric layer is made of ZnO, the bottom electrode is made of molybdenum and the top electrode is made of aluminium. The solid line 801 makes many loops indicating the presence of spurious resonance modes in this prior-art resonator.

The other resonator is a similar resonator, but the passivation layer has been opened and the top electrode material overlaps with the passivation layer. The resonator structure is similar to the resonator structure 700 presented in Fig. 7. The width of the frame-like zone where the passivation layer and the top electrode overlap is about 5 μm and the thickness of the passivation layer is 235 nm. The width and thickness of the frame-like zone have been chosen by adjusting the basic lateral resonance mode of an infinite slab comprising the same layer structure as the frame-like zone of the resonator comprises.

The effect of adding a frame-like layer to the resonator structure can be clearly seen in Fig. 8. The response of the resonator structure according to the invention is presented in dashed line 802 in Fig. 8. There are still some minor deviations from a

circle, but the response is dramatically better than that of the state-of-the-art, prior-art resonator.

It is also possible to use material that attenuates vibration to construct the acoustically different frame-like zone around the center area of the resonator. The dampening effect is demonstrated by studying the resonance modes of two resonator structures, one of which (900) comprises a dampening frame-like zone 903. The profile 901 of the studied resonators are presented in Fig. 9. The active area of the studied resonator structure, which is the thicker area in the middle of the profile 901, is 220 μm wide. The dampening effect is present at 10 μm wide zone 903 at the edge of the active area, within the active area.

The resonance frequencies of the structures are calculated, for example using FEM. When the resonance frequencies are calculated, the different acoustical dampening at the various regions of the structure can be taken into account by using a quality factor Q. The quality factor can be defined separately for each region. A large quality factor refers to small energy losses (losses are caused by the transformation of vibrational energy to heat), and small Q factor refers to large energy losses. The resonator structure 900 according to a second preferred embodiment of the invention is presented in Fig. 9. This structure was studied by assuming that the quality factor Q has value 1000 in the regions where there is no additional damping (i.e. region 902 and center area 904), and $Q = 50$ in the 10 μm wide zone 903 at the edge of the active area. These values of Q have no special meaning, they merely express the difference in the assumed damping properties at the various regions of the resonator structure. The acoustical thickness in the various region is illustrated on the vertical direction in Fig. 9. The acoustical thickness of region 903 is the same as that of the region 904, i.e. the frame-like zone simulated here differs from the center area only by its stronger attenuation properties.

Once the mechanical resonance modes are calculated and the piezoelectric effect is taken into account (either directly in the calculation or using different techniques), it is possible to present the behavior of the resonator structures using a Smith's chart. Fig. 10 presents the results of two simulations on a Smith's chart. The solid line 1001 represents the response of the state-of-the-art, prior-art BAW resonator where there is no frame-like dampening zone, and the loops indicating spurious resonance modes can be clearly seen. The dashed line 1002 presents the response of the resonator structure where there is a frame-like dampening zone. The dashed line resembles a circle and there are no loops. The loops have been suppressed to slight dents.

The dashed line in the Smith's chart indicates that a frame-like zone around the active area enhances the performance of a resonator structure. The dashed line is somewhat closer to the center of the chart than the solid lines. This means that also the basic resonance mode is slightly dampened, but the dampening is not very strong.

In this simulation the acoustically different frame-like zone around the center area of the resonator has only different attenuation properties than the rest of the resonator structure. The dampening effect can be caused, for example, by depositing a frame-like layer of a lossy film on top of the resonator structure. The lossy film may be, for example, polymer film. By adding a frame-like layer or otherwise adding dampening material to a practically uniform resonator structure, the acoustical thickness of the frame-like zone increases. Because both increasing the acoustical thickness of the frame-like zone and increasing the dampening in the frame-like zone, it is expected that a resonator structure where the combination of these modifications is used, has enhanced properties compared to prior-art resonators.

An exemplary resonator structure 1100 according to a third preferred embodiment of the invention is presented in Fig. 11. It comprises the bottom electrode 701, a piezoelectric layer 703 and a top electrode 702. The dampening material 1101 is deposited on the edge of the active resonator area, outside the active area. In the resonator structure 1100 the frame-like zone is both acoustically thicker and attenuates vibrations stronger than the active area of the resonator structure. If the dampening material 1101 is deposited over the top electrode 702 so that the frame-like zone is on the active area, it enhances the properties of the resonator even more efficiently.

BAW resonators are used here as an example of piezoelectric resonators, where the acoustically different frame-like zone around the active area enhances the properties of the resonator. The invention is not restricted to BAW resonators, and may be used to enhance the properties of crystal resonators, too.

The expressions indicating directions, such as top and bottom electrodes, refer to the position of an electrode compared to the substrate. A top electrode is on the opposite side of the piezoelectric layer as the substrate, and the bottom electrode is on the same side of the piezoelectric layer as the substrate. These and any other possible expressions indicating directions are used to make the description of the resonator

structure more eligible. These expressions do not restrict the resonator structures according to the invention in any way.

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CLAIMS

1. A resonator structure (700, 900, 1100) comprising two conductor layers (701, 702) and a piezoelectric layer (703) in between the conductor layers, **characterized** in that
- the resonator structure further comprises a frame-like zone (710) which confines a center area (720),
- the center area is within the active area (710, 720) of the resonator and
- the frame-like zone (710) is acoustically different from the center area (720).

2. A resonator structure (700, 1100) according to claim 1, **characterized** in that the frame-like zone (710) is acoustically thicker than the center area (720).

3. A resonator structure (900) according to claim 1, **characterized** in that the frame-like zone (903) is arranged to dampen vibration more effectively than the center area (904).

4. A resonator structure (1100) according to claim 1, **characterized** in that the frame-like zone (1101) is acoustically thicker than the center area and the frame-like zone (1101) is arranged to dampen vibration more effectively than the center area.

5. A resonator structure (1100) according to claim 1, **characterized** in that the resonator structure comprises at least one frame-like layer (1101).

6. A resonator structure (700) according to claim 1, **characterized** in that
- the layer structure of the frame-like zone (710) comprises all layers which extend over the center area (720) and
- the layer structure of the frame-like zone (710) comprises further at least one additional layer (704) which does not extend over the center area (720).

7. A resonator structure (700, 900) according to claim 1, **characterized** in that the frame-like zone (710, 903) is within the active area.

8. A resonator structure (1100) according to claim 1, **characterized** in that the frame-like zone (1101) is at least partly outside the active area.

9. A resonator structure (700) according to claim 1, **characterized** in that the width and acoustical thickness of the frame-like zone (710) is arranged so that the resonance frequency in infinitely long rectangular resonator, whose width is twice the width of the frame-like zone and whose acoustical thickness is the acoustical thickness of the frame-like zone, is substantially the same as the cut-off frequency of the center area (720).

10. A resonator structure according to claim 1, **characterized** in that it further comprises a second piezoelectric layer in between the conductive layers and a conductor layer in between the piezoelectric layers.

11. A filter comprising at least one resonator structure which comprises two conductor layers and a piezoelectric layer in between the conductor layers, **characterized** in that
- the resonator structure further comprises a frame-like zone (710) which confines a center area (720),
- the center area is within the active area (710, 720) of the resonator and
- the frame-like zone (710) is acoustically different from the center area (720).

12. Mobile communication means comprising at least one resonator structure, which comprises two conductor layers and a piezoelectric layer in between the conductor layers, **characterized** in that
- the resonator structure further comprises a frame-like zone (710) which confines a center area (720),
- the center area is within the active area (710, 720) of the resonator and
- the frame-like zone (710) is acoustically different from the center area (720).

Abstract

A resonator structure (700, 900, 1100) according to the invention comprises two conductor layers (701, 702) and a piezoelectric layer (703) in between the conductor layers. It is characterized in that it further comprises a frame-like zone (710) which confines a center area (720), the center area is within the active area (710, 720) of the resonator and the frame-like zone (710) is acoustically different from the center area (720).

Fig. 7

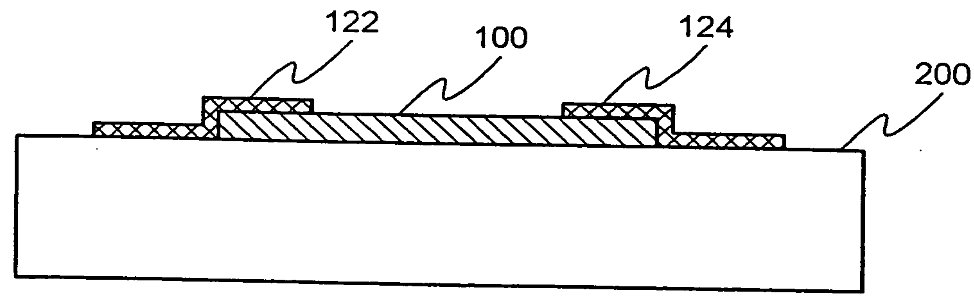

Fig. 1
PRIOR ART

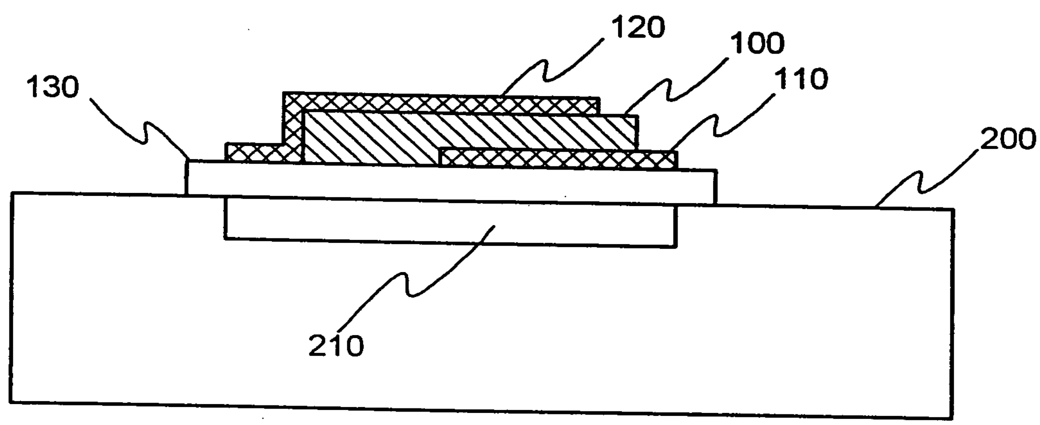

Fig. 2
PRIOR ART

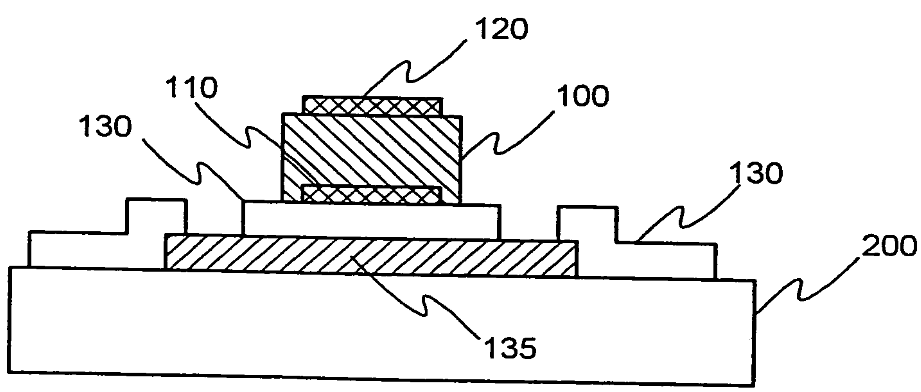

Fig. 3
PRIOR ART

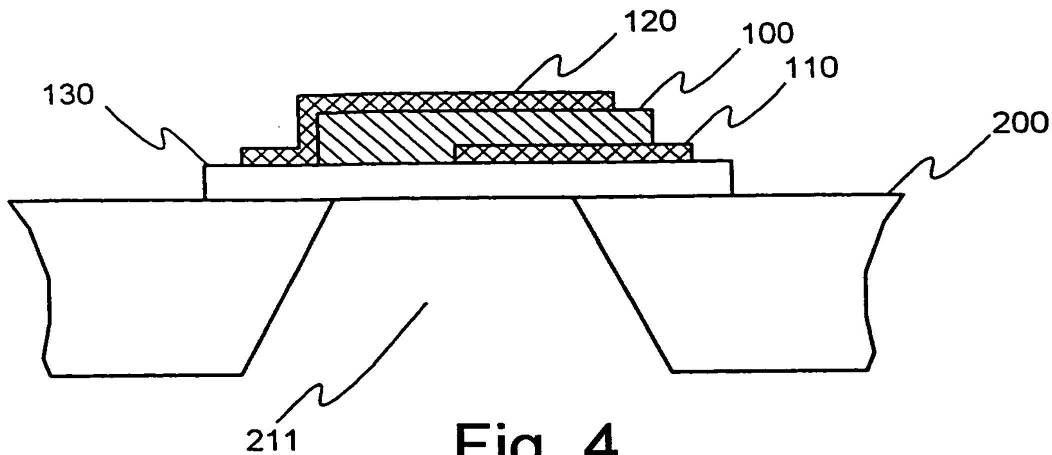

Fig. 4
PRIOR ART

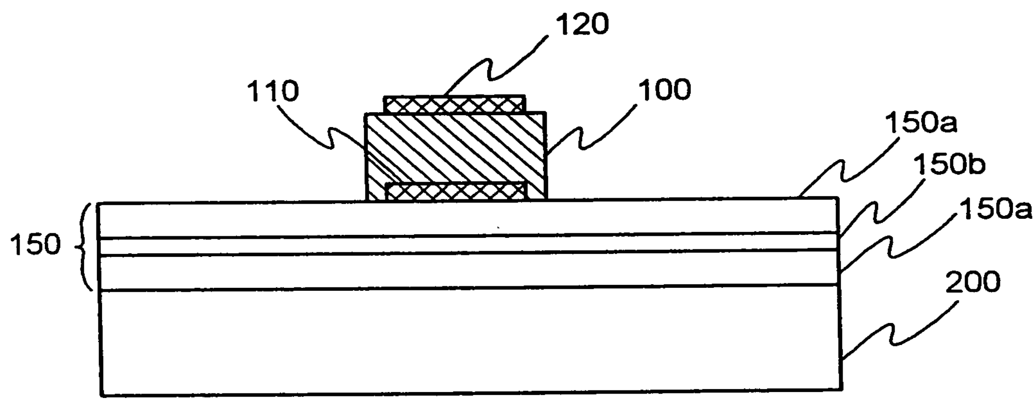

Fig. 5
PRIOR ART

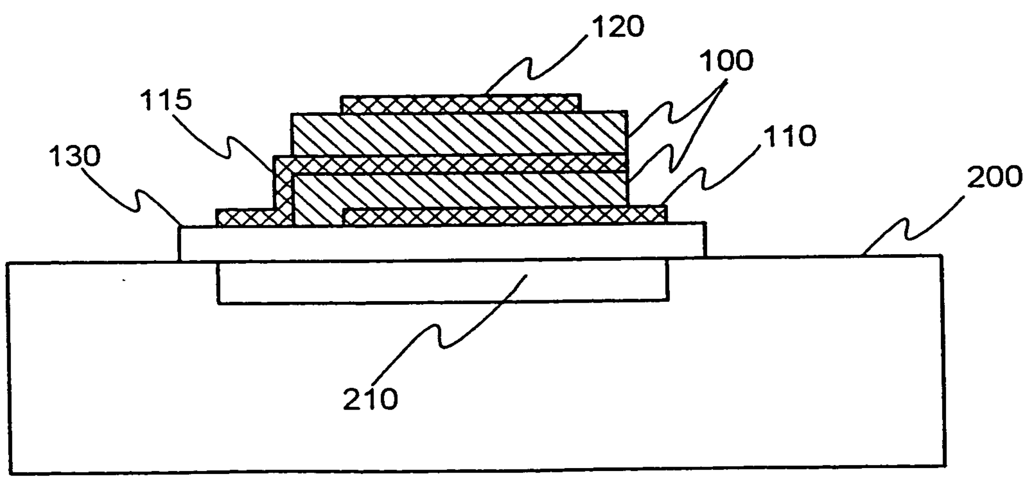

Fig. 6
PRIOR ART

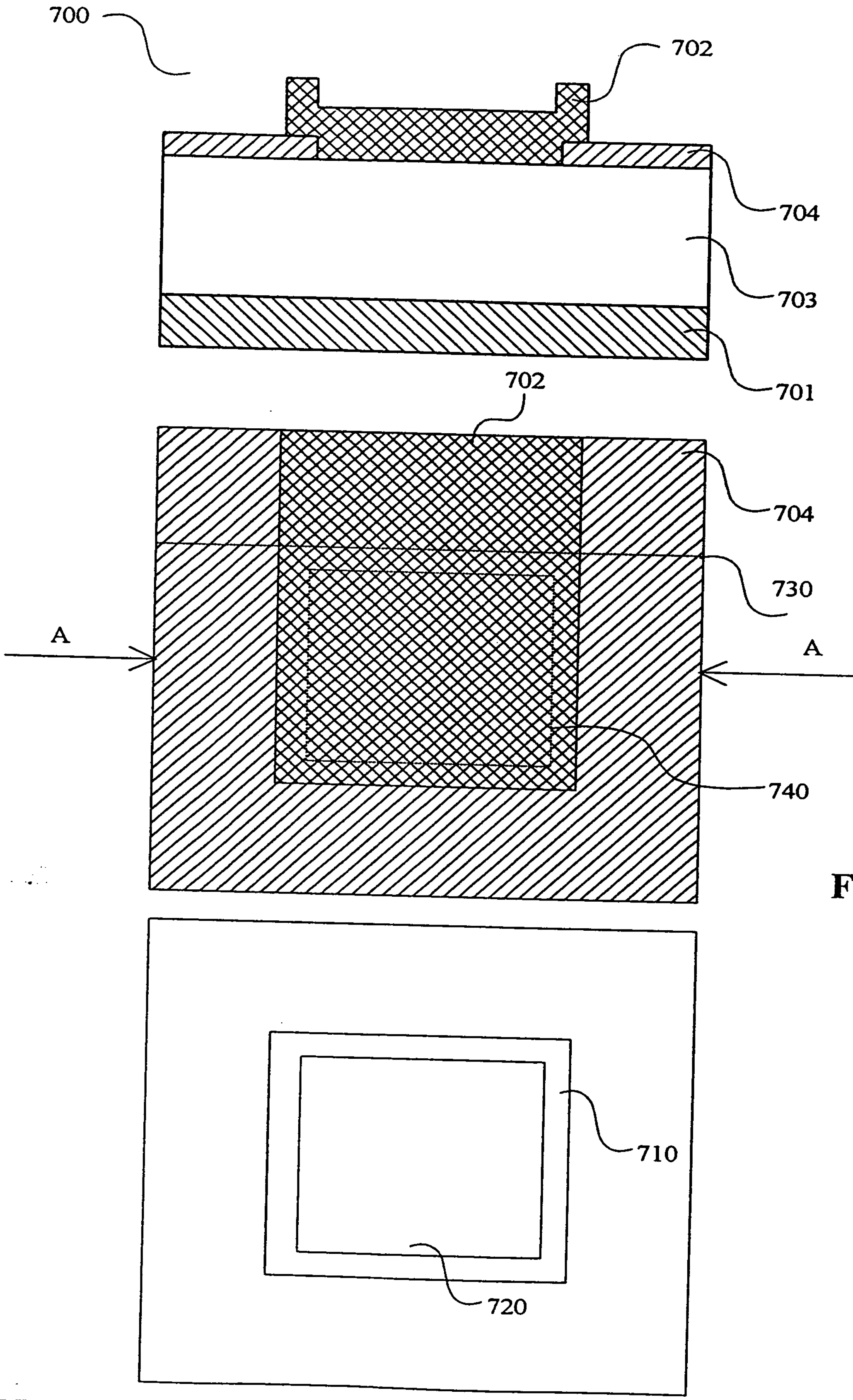

FIG. 7

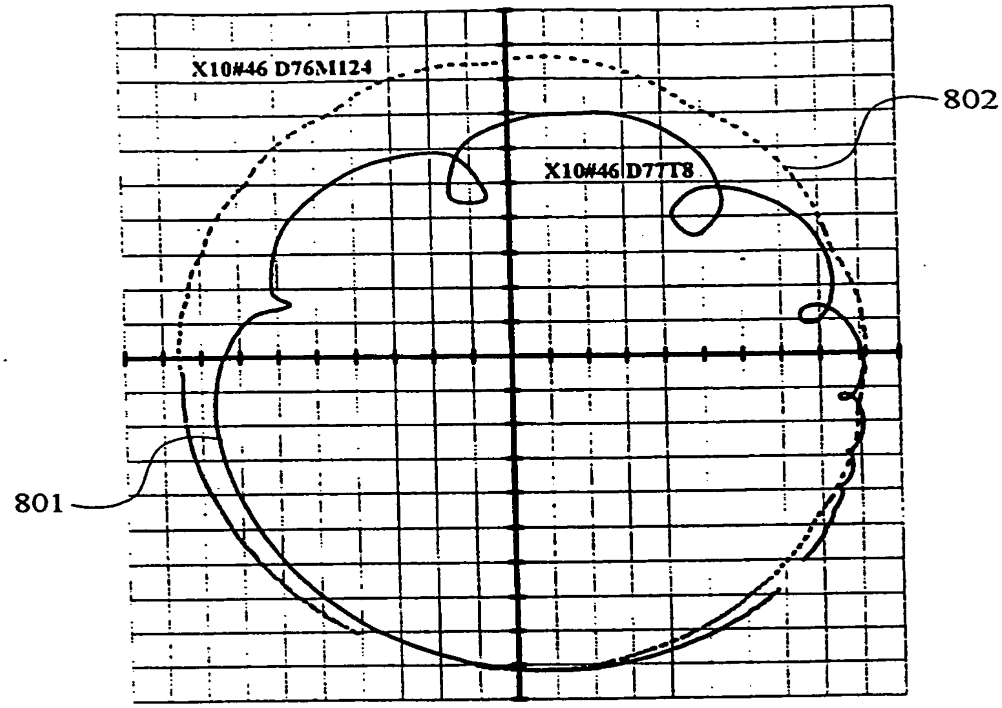
X10#46 D76M124
X10#46 D77T8
802
801

FIG. 8

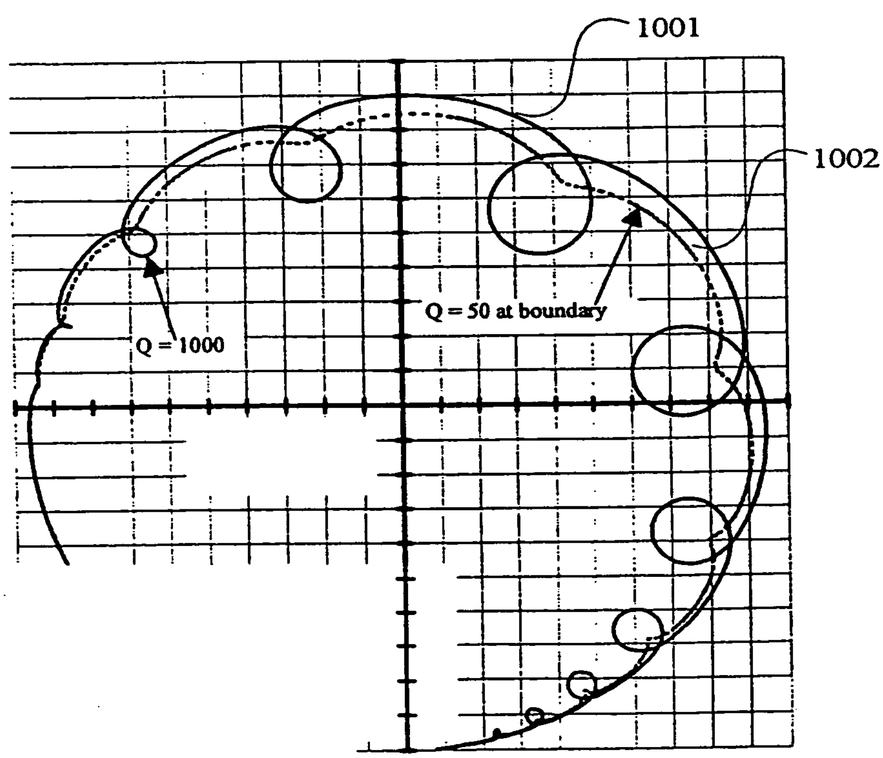
1001
1002
Q = 50 at boundary
Q = 1000

FIG. 10

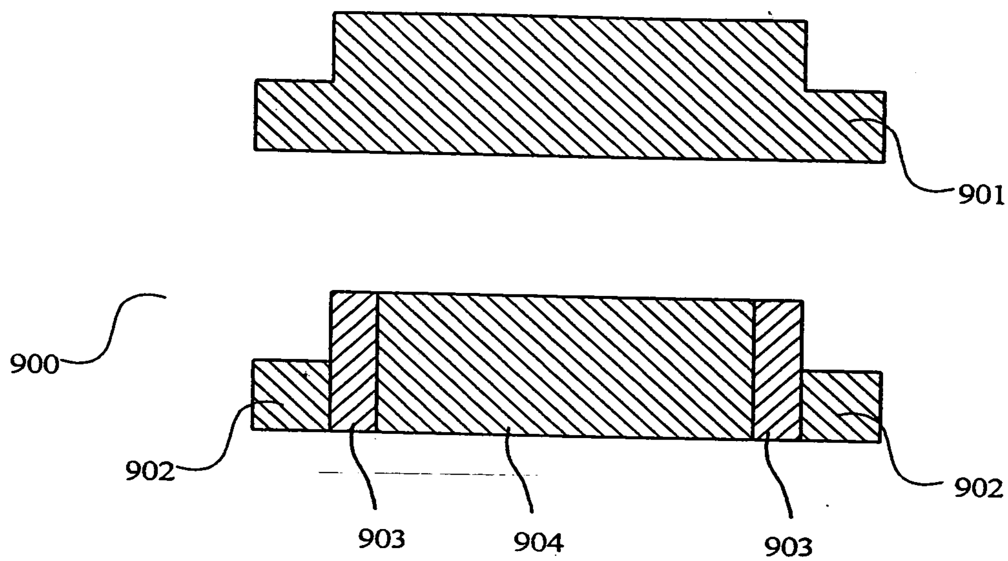

FIG. 9

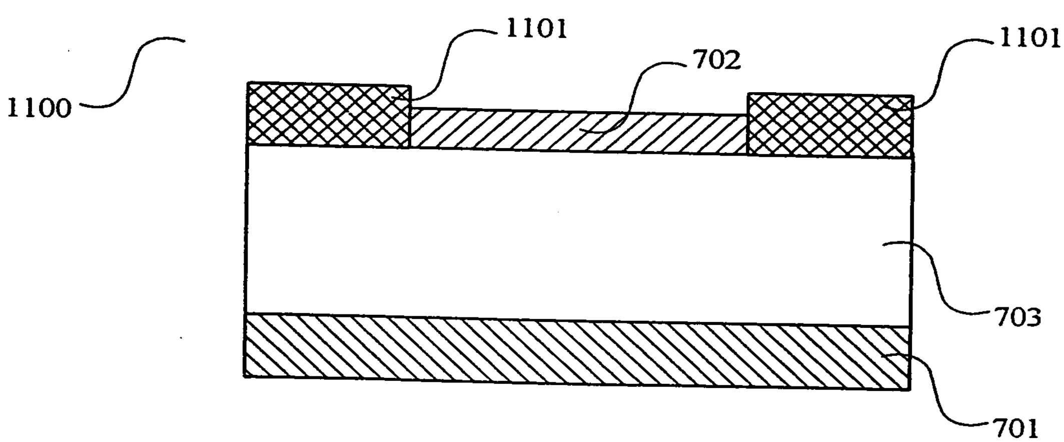

FIG. 11